THE GREEN TURTLE, *CHELONIA MYDAS*, IN QUEENSLAND: FEEDING ECOLOGY OF IMMATURE TURTLES IN MORETON BAY, SOUTHEASTERN QUEENSLAND

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The diet of immature Green Turtles, *Chelonia mydas*, from the Moreton Banks and Flathead Gutter sites of Moreton Bay, included the available seagrass species and some of the available species of algae. Some animal material was ingested, as were fruits of the Grey Mangrove, *Avicennia marina*. Volumetrically, the seagrass *Halophila ovalis* and the red algae *Gracilaria cylindrica* and *Hypnea spinella* were the most important components of the diet. ❒ *Green Turtles, Chelonia, feeding ecology, diet, southeastern Queensland, Australia.*

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The Green Turtle, *Chelonia mydas*, is found in most tropical and sub-tropical seas (Groombridge & Luxmoore, 1989). It is the only marine turtle to feed principally on aquatic vegetation (Mortimer, 1982; Bjorndal, 1997), but will also include animal material (Hirth, 1971; Bjorndal, 1997) and mangrove vegetation and fruits in the diet (Pritchard, 1971; Pendoley & Fitzpatrick, 1999; Limpus & Limpus, 2000). Wild populations of Green Turtles feed primarily on seagrass or algae (Bjorndal, 1980; Mortimer, 1982; Bjorndal, 1997). There is, however, ambiguity as to whether *C. mydas* is a selective feeder, ingesting seagrass (or algae) preferentially in an area where both dietary items are available. In a review of the feeding ecology of marine turtles, Mortimer (1982) suggested that Green Turtles consumed algae only when seagrass were unavailable. Bjorndal (1980) reported that immature Green Turtles feeding in the Bahamas rarely consume algae, although it is present in large quantities. Garnett et al. (1985) examined the diet of Green Turtles feeding in Torres Strait, Australia, and could find no evidence to support the theory that turtles feed on algae only when seagrasses were unavailable. Brand (1995) examined the feeding behaviour of juvenile Green Turtles in Flathead Gutter, Moreton Bay and found that individuals were targeting algae, primarily *Gracilaria*.

There is a paucity of detailed analyses on the diet of *C. mydas* in Australian waters. It feeds on algae (Limpus, 1978; Limpus & Reed, 1985a; Garnett et al., 1985), seagrass (Lanyon et al., 1989), macro-zooplankton (Limpus 1978) and mangrove vegetation and fruits (Read, 1991; Limpus & Limpus, 2000). Forbes (1994) analysed stomach lavage samples from 518 Green Turtles feeding on the reefs surrounding Heron Island, and found that the diet was composed of 38 species of red algae, 21 species of green algae, and 10 species of brown algae. *C. mydas* in this reefal environment were also consuming small amounts of animal material (Forbes, 1994). These data however, are primarily from tropical and algal-based reefal habitats. The present work details the diet of the population of immature Green Turtles feeding in inshore areas of Moreton Bay, southeastern Queensland.

MATERIALS AND METHODS

The turtles of the present study are a subset of those examined for determining the population structure of *C. mydas* in Moreton Bay (Limpus et al., 1994). Turtles were captured in the inter-tidal and adjacent sub-tidal regions of the Moreton Banks (27°20' S, 153°24' E) and Flathead Gutter (27°20'30" S, 153°24'50"E), using the 'turtle rodeo' technique (Limpus, 1978; Limpus & Walter, 1980). Attempts were made to catch all turtles sighted and few evaded capture. Turtles were tagged in the axillary tagging position (Limpus, 1992). The midline curved carapace length (CCL) was measured using a flexible tape (± 0.5cm) and turtles weighed using a Salter

Spring balance (± 0.5kg). The sex and maturity of the majority of Green Turtles were determined via a visual examination of the gonads using laparoscopy (Limpus, 1985; Limpus & Reed, 1985a; Limpus, 1992). Turtles not examined by laparoscopy and whose CCL was less than minimum breeding size for *C. mydas* that breed in eastern Australia (<90cm: Limpus et al., 1984) were assumed to be immature. Turtles were assigned to size classes on CCL: CCL < 65cm = juvenile (J); CCL 65< 90cm = sub-adults (SA); CCL > 90cm and with immature gonads differentiating towards an adult condition = pubescent (P).

Lavage samples were collected from the lower oesophagus (=crop; Thompson, 1980) by stomach flushing (Forbes & Limpus, 1993). Lavage samples of approximately 60-100 grams (wet weight) were usually collected and preserved in 70% ethanol until analysis. Samples were scanned qualitatively to identify contents: seagrasses were identified from keys of Lanyon (1986); algae and Mangrove fruits were identified from keys of Cribb & Cribb (1985). Relative volumes of species in the lavage samples were estimated using principles of stereology (Schaefer, 1970; Gander, 1970). To calculate the percent relative volume of a particular dietary item, the main lavage sample was mixed in a flat-bottomed tray until visually homogeneous. Sufficient sub-sample was randomly removed from the main sample so as to evenly cover the base of a petri dish (85mm diameter). The sub-sample was then analysed under a dissecting microscope at X7, providing a field of view of 15.5mm. Nine fields of the petri dish were examined quantitatively with a graticule that had 36 endpoints of measurement. The first field was selected by placing the petri dish on the microscope stage at a pre-determined co-ordinate: subsequent sites were selected by rotating the petri dish to aligning marks on the side of the petri dish, which sampled the dish without overlap. The relative volumes (%) of the species in the sub-sample were then calculated using formulae (Gander, 1970). Due to the freshness of the lavage samples, most material could be identified to species.

Statistical analyses were performed using the SAS statistics Software Package (1988). The data were initially transformed using an arcsin ($\sqrt{P}$) correction for proportional data to improve normality and variance homogeneity. Analysis of variance (ANOV) were performed using the GLM procedure. Unless otherwise specified, means are ± 1 standard deviation.

STUDY SITE. The Moreton Banks and Flathead Gutter sites, in Moreton Bay, were described in detail by Limpus et al. (1994) and Read (1991). A major geographical feature of the eastern side of Moreton Bay is a large delta comprising the Moreton and Maroom Banks, which are situated between Peel Island, Moreton Island, Crab Island and North Stradbroke Island. These series of shallow sub- and intertidal banks were formed and are maintained by the tidal movement of oceanic and inshore waters through the Rous Channel, the main channel facilitating water flow from the eastern section of Moreton Bay (Milford & Church, 1976). The Moreton Banks (27°24'S - 27°19'S) form the northern portion of this delta. Mean air temperatures at Cape Moreton (27°03'S, 153°27'E) can vary between 26.7°C in January to 13.1°C in July (Bureau of Meteorology, 1999). Surface water temperatures follow the fluctuations of the ambient air temperatures but are generally 2-3°C higher. The Moreton Banks are covered in most areas by 2-6m of water at high tide and varying proportions of the banks are exposed at low tide (Anon, 1987). The Moreton Banks cover ~6290ha, with some 2513ha of seagrass meadow and another 3777ha of sparse or patchy seagrass (Hyland et al., 1989). Dominant vegetation of the Moreton Banks includes seagrasses (*Halophila ovalis, H. spinulosa, Halodule uninervis, Zostera capricorni, Syringodium isoetifolium*, Hyland et al., 1989) and macro-algae (*Sargassum* sp., *Hypnea spinella, Gracilaria cylindrica, Hydroclathrus clathratus, Codium fragile*). The eastern margin of these banks and Crab Island are fringed by the Grey Mangrove, *Avicennia marina* (Dowling, 1986). A narrow channel that passes between Crab and Moreton Islands, Flathead Gutter, has a sandy substratum, ~3m deep at high tide (Anon, 1987), with a covering of seagrasses and algae on the sloping margins. Seagrass flats bound Flathead Gutter on either side of the channel, with Grey Mangroves growing along their eastern margin.

RESULTS

Between April and October 1991, 199 Green Turtles were captured and sampled for diet from the Moreton Banks and Flathead Gutter, with 31 being recaptured and re-sampled (some more than once), increasing the number of lavage samples to 240. Sex ratio and size classes were

TABLE 1. Sex ratio and size class distribution of immature *Chelonia mydas* sampled from the Moreton Banks and Flathead Gutter sites within Moreton Bay, between April and October 1991.

Sex	Size Class			Total(%)
	Juvenile	Sub-adult	Pubescent	
Female	89	19	1	109(66.5)
Male	39	16	-	55(33.5)
Unknown	27	8	-	35
Total	155(77.9%)	43 (21.6%)	1(0.5%)	199

taken (Table 1). Turtles sampled were predominately from the 10-20kg weight range.

Dietary items identified from lavage samples are listed (Table 2).

Site-specific differences in the mean relative volumes of the common food items ingested were detected. Immature turtles from the Moreton Banks site consumed significantly more *Halophila ovalis* and *Halophila spinulosa* compared to animals from Flathead Gutter, but less *Halodule uninervis, Zostera capricorni* and *Gracilaria cylindrica* (Table 3). There were no significant differences between sites for the amount of *Hypnea spinella* consumed.

On the Moreton Banks the seagrass *Halophila*

TABLE 3. Site-specific dietary differences for immature *Chelonia mydas* from the Moreton Bay region.

Dietary Item	F value	p	Study site mean relative volume ingested (%)	
			Moreton Banks	Flathead Gutter
Halophila ovalis	142.3	0.0001	41.9 ± 0.5	11.4 ± 0.5
Halophila spinulosa	5.6	0.05	5.8 ± 0.4	2.1 ± 0.4
Halodule uninervis	153.1	0.0001	1.1 ± 0.2	6.6 ± 0.2
Zostera capricorni	76.1	0.0001	3.5 ± 0.5	4.3 ± 0.2
Hypnea spinella	0.07	0.08	15.0 ± 0.6	23.0 ± 0.6
Gracilaria cylindrica	76.2	0.0001	11.3 ± 0.7	39.7 ± 0.5

ovalis occurs in the samples with high frequency (92%) and also in the highest mean relative volumes (41.9±0.5%) (Table 4). *Halophila ovalis* contributed mean relative volumes in excess of 30% for 65% of the lavage samples it was identified from. This compares to the red algae, *Hypnea spinella* and *Gracilaria cylindrica,* which occurred in lavage samples with high frequency (63.7% and 31% respectively), but with lower mean relative volumes (15±0.6% and 11.3±0.7%). The red algae, *Hypnea spinella* and

TABLE 2. Dietary items identified in lavage samples from immature *Chelonia mydas* sampled from the Moreton Banks and Flathead Gutter sites within Moreton Bay, between April and October 1991.

Seagrasses	Family Potamogetonaceae *Halodule uninervis* *Syringodium isoetifolium* *Zostera capricorni* Family Hydrocharitacae *Halophila ovalis* *Halophila spinulosa*
Algae	Division Rhodophyta *Hypnea spinella* *Gracilaria cylindrica* *Chondria* sp Division Phaeophyta *Hydroclathrus clathratus* Division Chlorophyta *Cladophoropsis sundanensis* *Caulerpa mexicana*
Animal material	Phylum Cnidaria Class Scyphozoa *Catostylus mosaicus* Class Anthozoa *Stichodactyla haddoni* Phylum Arthozoa Class Crustaea *Portunus pelagicus*
Mangrove	Angiospermae Verberaceae *Avicennia marina*
Miscellaneous	Shell Fragments Plant material Animal material

Gracilaria cylindrica contributed in excess of 30% in 13.0% and 4% of samples they were identified from. The remaining seagrasses were identified with fairly high frequency but their mean relative volume contribution was usually low (<10%). The cnidarian, *Catostylus mosaicus*, was only identified from nine samples, but its mean relative volume contribution was high (15.4±1.6%). Fruits of the Grey Mangrove were completely absent in the diet of turtles on the Moreton Banks as was the brown alga *Hydroclathrus clathratus.*

In Flathead Gutter (Table 5), *Halophila ovalis* occurred in samples with lower frequency and in lower mean relative volumes compared to immature Green Turtles feeding on the Moreton Banks, and the algae *Hypnea spinella* and *Gracilaria cylindrica* occurred with high frequencies and high mean relative volumes. The seagrasses *Halodule uninervis* and *Zostera capricorni* were identified with high frequency in lavage samples from this site (96.9% and 90.6% respectively), but contributed little in terms of

TABLE 4. Volumetric analysis of dietary items ingested by immature *Chelonia mydas* from the Moreton Banks site within Moreton Bay, between April and October 1991 (n=113).

Dietary Item	Number of lavage sample with relative volumes				Mean ± STD	Frequency (%)	Total
	<5%	5<30%	30<50%	>50%			
Seagrasses							
Halophila ovalis	6	33	21	44	41.9 ± 0.5	92.0	104
Halophila spinulosa	31	12	2	0	5.8 ± 0.4	39.8	45
Halodule uninervis	44	3	0	0	1.1 ± 0.2	41.6	47
Zostera capricorni	25	5	0	0	3.5 ± 0.5	26.5	30
Syringodium isoetifolium	8	3	1	0	7.4 ± 1.0	10.6	12
Algae							
Hypnea spinella	38	21	4	9	15.0 ± 0.6	63.7	72
Gracilaria cylindrica	17	14	3	1	11.3 ± 0.7	31.0	35
Hydroclathrus clathratus	-	-	-	-	-	-	-
Chondria sp.	0	0	0	1	76.0	0.9	1
Cladophoropsis sundanensis	0	1	0	0	7.1	0.9	1
Caulerpa mexicana	3	1	0	0	2.2 ± 0.9	3.5	4
Mangrove							
Avicennia marina	-	-	-	-	-	-	-
Animal material							
Stichodactyla haddoni	1	2	0	0	6.3 ± 1.4	2.7	3
Catostylus mosaicus	3	5	0	1	15.4 ± 1.6	8.0	9
Portunus pelagicus	-	-	-	-	-	-	-
Unidentified animal	11	1	0	0	1.3 ± 0.4	10.6	12
Miscellaneous							
Unidentified plant	3	0	0	0	1.7 ± 1.0	2.7	3
Shell fragments	26	3	0	0	1.5 ± 0.3	25.7	29

mean relative volume (6.6±0.2% and 4.3±0.2% respectively). Fruit of *Avicennia marina* were present in 40.2% of lavage samples with a mean relative volume of 8.8±0.4%.

DISCUSSION

The diet of immature Green Turtles from the Moreton Banks and Flathead Gutter (Tables 4, 5) included algae and seagrasses, fruit of the Grey Mangrove, cnidarians *Catostylus mosaicus* and *Stichodactyla haddoni* and the crustacean *Portunus pelagicus*. Ross (1985) reported that Green Turtles in the northern Indian Ocean ingested seagrasses *Halophila ovalis* and *Halodule uninervis* and most turtles sampled had large quantities of algae in the stomach. Limpus & Reed (1985a) identified Chlorophyta, Phaeophyta and Rhodophyta in last bite samples from *C. mydas* on Heron Reef. Forbes (1994) found that *C. mydas* feeding on reefal habitat around Heron Island were feeding on 38 species of red algae, 21 green algae and 10 brown algae. Based on the stomach contents of 5 *C. mydas* stranded while feeding near the Sir Edward Pellew Island, NT, the major diet species were *Halodule pinifolia*, with smaller amounts of *Halodule uninervis* and *Halophila ovalis* (Limpus & Reed, 1985b). Species representing the three Divisions of algae and the seagrasses *Cymodocea* sp., *Thalanssia hemprichi* and *Halophila spinulosa* were identified in stomach contents from Green Turtles in Torres Strait (Garnett et al., 1985). Lanyon et al. (1989) reported Green Turtles in the shallow bays and estuaries in Australia feed un- selectively on the available species of seagrass. Brand (1995) found that juvenile Green Turtles in Flathead Gutter were feeding on 3 species of seagrass and 3 species of algae. Based on the content of 20 lavage samples, Green Turtles in this site were ingesting some animal material, but fragmentation meant that forage groups could not be identified to species level (Brand, 1995).

Immature Green Turtles were selecting to feed on the seagrasses *Halophila ovalis* and *Halodule uninervis*. These food items have a sparse distribution in the Moreton Banks and Flathead

TABLE 5. Volumetric analysis of dietary items ingested by immature *Chelonia mydas* from the Flathead Gutter site within Moreton Bay, between April and October 1991 (n=127).

Dietary Item	Number of lavage sample with relative volumes				Mean ± STD	Frequency (%)	Total
	<5%	5<30%	30<50%	>50%			
Seagrasses							
Halophila ovalis	34	23	5	1	11.4 ± 0.5	49.6	63
Halophila spinulosa	16	2	0	0	2.1 ± 0.4	14.2	18
Halodule uninervis	57	66	0	0	6.6 ± 0.2	96.6	123
Zostera capricorni	79	36	0	0	4.3 ± 0.2	90.6	115
Syringodium isoetifolium	2	0	0	0	1.1 ± 0.6	1.6	2
Algae							
Hypnea spinella	21	23	11	10	23.0 ± 0.6	51.2	65
Gracilaria cylindrica	6	33	26	35	39.7 ± 0.5	78.7	100
Hydroclathrus clathratus	8	0	0	0	1.8 ± 0.4	6.3	8
Chondria sp.	-	-	-	-	-	-	-
Cladophoropsis sundanensis	1	1	0	0	14.3 ± 3.1	1.6	2
Caulerpa mexicana	-	-	-	-	-	-	-
Mangrove							
Avicennia marina	23	27	0	1	8.8 ± 0.4	40.2	51
Animal material							
Stichodactyla haddoni	6	4	0	1	11.7 ± 1.2	8.7	11
Catostylus mosaicus	2	2	0	0	8.8 ± 1.6	3.1	4
Portunus pelagicus	1	0	0	0	-	0.8	1
Unidentified animal	22	1	0	0	1.1 ± 0.2	18.1	23
Miscellaneous							
Unidentified plant	4	0	0	0	1.5 ± 0.5	3.1	4
Shell fragments	17	0	0	0	0.9 ± 0.2	13.4	7

Gutter sites (Hyland et al., 1989), and often form seagrass communities with *Zostera capricorni* and *Halophila spinulosa* (Young & Kirkman, 1975). Selective feeding has been reported in previous studies on the feeding ecology of Green Turtles. Bjorndal (1980) reported that immature Green Turtles selected to feed on one species of seagrass, *Thalassia testudinum*, although algae were abundant in the feeding ground. This preference for *T. testudinum* was also noted for immature Green Turtles feeding in Nicaragua (Mortimer, 1981). Mendonca (1983) reported that immature Green Turtles in Mosquito Lagoon, Florida, fed primarily on seagrasses with algae making up a small proportion of the diet, although algae were abundant in the feeding ground. Balazs (1980) suggested that relative abundance and feeding selectivity determined the habits of Hawaiian Green Turtles and Ross (1985) attributed the differential abundance of algal species in the habitat and diet of Green Turtles in Oman to selective feeding. Forbes (1994) also concluded that Green Turtles resident on Heron Island reef did not ingest algal species based on relative abundance, but fed selectively.

Selection for diet based on algae or seagrass appears to be a feature of distinct populations of Green Turtles or it may be a reflection of insufficient sampling over a limited temporal period. Green Turtles are opportunistic grazers that modify their diet according to composition of the forage. Mortimer (1981) studied the feeding ecology of *C. mydas* from 3 feeding sites in Nicaragua and detected dietary differences attributed to the composition of the local forage and not selectivity. Garnett et al. (1985) studied diets of Green Turtles from 2 sites in Torres Strait, and although there was some selection for soft red algae, no support was found for the hypothesis that turtles fed on algae only when seagrasses were unavailable. Garnett et al. (1985) concluded that the "geographical variation in diets appears to be determined by the relative availability of seagrass and algae and the structure of the local herbivore community." Although some feeding selectivity for seagrasses

Halophila ovalis and *Halodule uninervis* was detected in immature Green Turtles from Moreton Banks, they did not exhibit the selection for a monospecific diet as suggested by Bjorndal (1980). Turtles ingested the seagrasses and algae that were available in the specific feeding area. There is no evidence from this study to support the hypothesis that turtles ingest algae only when seagrasses are unavailable.

Immature *C. mydas* from the Flathead Gutter site were also selecting to feeding on the fruits of the Grey Mangrove. To ingest the fruits of the Grey Mangrove would involve a distinct change from grazing on seagrasses and algae. Green Turtles would either have to forage for fruit floating on the surface or move into the mangle at high tide and feed on the fleshy cotyledons connected to the stem of seedlings or fruit still attached to the tree but covered by water.

There have been few reports of Green Turtles feeding on mangrove vegetation or fruit. Pritchard (1971) recorded Green Turtles in the Galapagos Islands feeding on the foliage and roots of mangroves and Pendoley & Fitzpatrick (1999) recorded Green Turtles in Western Australia feeding on the leaves of the Grey Mangrove. Green Turtles in Shoalwater Bay, an inshore feeding ground on the central Queensland coast, feed on the foliage and fruits of *A. marina*, and rarely on the fruits of *Rhizophora* sp. (Limpus & Limpus, 2000). Vegetation from the mangrove *Rhizophora* sp. has also been recorded from stomach contents of Hawksbill Turtles, *Eretmochelys imbricata* (Bjorndal, 1997). The finding that Green Turtles in Flathead Gutter regularly feed on fruit of the Grey Mangrove poses the question as to whether *C. mydas* may represent a previously unrecognised grazer on mangroves. There are few reports on predators of mangroves. Cattle will freely eat the leaves and fallen seeds of the White Mangrove *Avicennia marina* var. *resinifera* (Everist, 1969). Chapman (1976) reports that large crabs, *Sesarma meinerti* and *S. smithi* are vegetarians, eating fallen leaves and seedlings with the result that they can have a distinct effect upon the rate of regeneration of mangrove forests. There are many sites within Moreton Bay that support large mangrove communities (Dowling, 1986). Many of these are adjacent to deepwater areas and may offer access to this resource for Green Turtles. The level of grazing pressure exerted by *C. mydas* on mangrove vegetation in Moreton Bay remains unquantified, though the turtles may be having a significant impact on regeneration of seedlings.

The diet of immature Green Turtles in the Moreton Banks and Flathead Gutter were similar to other studies when comparing the amount of animal material ingested. Sixty three (26.3%) of the lavage samples analysed contained some animal material. Garnett et al. (1985) recorded animal material in 52.3% of the 44 stomach contents analysed from *C. mydas* in Torres Strait. Animal material contributed 1.4% of the total dry weight of 243 stomach contents of *C. mydas* from Nicaragua (Mortimer, 1981). Forbes (1994) also recorded animal material from lavage samples taken from 518 Green Turtles at Heron Island. Captive Green Turtles thrive on a diet of fish and crustaceans (Mortimer, 1981) and pelleted food (Wood & Wood, 1981). Green Turtles can digest formulated high protein diets with a high degree of efficiency (Wood & Wood, 1981), and, although it usually constitutes a small proportion of the diet, animal protein may play an important role in the nutrition of this species.

Based on frequency and relative volumes of animal material in lavage samples from immature Green Turtles on the Moreton Banks and Flathead Gutter, we conclude that these turtles are deliberately selecting to feed on these dietary items rather than ingesting them incidentally. To feed selectively on these dietary items involved a distinct change in feeding behaviour that is very different from grazing on seagrasses or algae. To feed on *Catostylus mosaicus*, the turtle must rise into the water column to encounter the cnidarian and turtles have been observed feeding on the cnidarian whilst at the surface (pers. obs., MAR & CJL). The anemone, *Stichodactyla haddoni*, could have been ingested whilst grazing on seagrasses and algae, but it was identified from lavage samples in relative volumes large enough to suggest that it had been deliberately ingested.

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